

## RESIDUAL STRESSES ANALYSIS OF LAMINATED GRAPHITE/EPOXY COMPOSITE PLATES USING HYPERMESH

CH. SIVA RAMAKRISHNA<sup>1</sup>, MOTURI RAM GANESH<sup>2</sup>, REDDI VISWESWARA RAO<sup>3</sup>  
& PINREDDY DHARMATEJA<sup>4</sup>

<sup>1</sup>Associate professor, Vignan's Institute of Information Technology, Visakhapatnam, Andhra Pradesh, India

<sup>2,3,4</sup>UG Students, Vignan's Institute of Information Technology, Visakhapatnam, Andhra Pradesh, India

### ABSTRACT

*The structures made of laminated composites are used in various engineering applications like in military, aerospace and automotive Industries. To design the composite, the precision learning of structural behavior is required. In this connection, estimation of residual stresses is an important criterion for predicting the behavior of laminated composite. Residual stresses are developed when the laminate is subjected to temperature change. The residual stresses of the composite laminate are estimated by considering the temperature change of -75° on the specimen and analytical method is used for the same. In the analytical method, the stresses are developed for piles of orientation (0°/90°) in the laminated composite and simulate the analytical values with numerical analysis is developed for validation.*

*This study aims to examine the residual stresses of the Graphite/Epoxy layer composite through analytical and simulated methods using HYPERMESH. The residual stress analysis includes all the types of stress behavior in diagrammatic form and results are developed. For validation, the simulated values and the analytical values are compared with the required accuracy.*

**KEYWORDS:** Laminate Composite, Analytical Method, Numerical Analysis, Residual Stress & HYPERMESH

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### INTRODUCTION

Matrix phase and Dispersed phase is greatly influenced in composite material and the properties of these different from the constituents of composites. **Graphite Polymer Composite:** Graphite, which is composed of the hexagonal lattice with  $sp^2$  –hybridized carbon atoms in a single layer, has received tremendous attention in both scientific and industrial areas. It is the strongest material and has other remarkable qualities, including high thermal stability and electron mobility as well as large surface area and high aspect ratio that elevate its potential for use as filler in the high-performance polymer. **Residual Stresses:** The main effects of residual stresses are a reduction in strength, and shape distortion. The stresses at the fiber matrix, lamina, laminate and structural levels all affect the strength of the component, where only lamina-laminate and structural level stresses affect dimensional stability to any significant degree. **Composites Analysis:** For analysis on layered composite plates the FEM (Finite Element Method) is mostly used which uses the principles of engineering and physics. FEM is basically a numerical tool to attain the applications. It uses the partial differential equations specified in boundary conditions. **HYPERMESH:** Over the last 20 years, Hyper Mesh has evolved into the leading premier pre-processor for the concept and high fidelity modeling. The improved meshing capabilities, advanced geometry, and rapid model generation are the

advanced features of the software. High-quality mesh in complex systems is the core competencies. The software is well supported in the areas of advanced editing and visualization.

## LITERATURE REVIEW

Stango R. J. and Wang S. S [1] A study of process-induced stresses in advanced fiber-reinforced composite laminates are presented. An analysis of the residual thermal stresses is conducted on the basis of laminate thermoelasticity theory in conjunction with a quasi-three-dimensional finite element method. Huang X. G., Gillespie J. W. Jr. and Bogetti T. A [2] A study of process-induced stress and deformation in thick-section thermosetting composite laminates is presented. A methodology is proposed for predicting the evolution of residual stress development during the curing process. A one-dimensional cure simulation analysis is coupled to an incremental laminated plate theory model to study the relationships between complex gradients in temperature and degree of cure, and process-induced residual stress and deformation. Thermal expansion and cure shrinkage contribute to changes in materialspecific volume and represent important sources of internal loading included in the analysis. Temperature and degree of cure gradients that develop during the curing process represent fundamental mechanisms that contribute to stress development not considered in traditional residual stress analyses of laminated composites. The results clearly indicate that the mechanics and performance of thick-section thermoset laminates are strongly dependent on processing history. Hahn, H. T [3] Residual stresses in composites are induced during fabrication and by environmental exposure. The theory, formulated can describe the shrinkage commonly observed after a thermal expansion test. Comparison between the analysis and experimental data for  $[0_2/\pm 45]_s$  laminates of various material systems indicates that the residual stress-free temperature can be lower than the curing temperature, depending on the curing process. Effects of residual stresses on ply failure, including the acoustic emission characteristics are discussed. R. C. Novak and M. A. DeCrescent [4] Residual thermal stresses are present in cross-plyed graphite-epoxy composites due to the anisotropic thermal and mechanical properties of the individual layers. Experimental measurements and analytical calculations of the thermal stress induced in two different cross-plyed composites during fabrication are presented and shown to be in good agreement. The occurrence of cracking in certain composites is explained in terms of the transverse tensile strength of the unidirectional composite layers and the stress developed.

R. A. Schapery [5] Bounds on effective thermal expansion coefficients of isotropic and anisotropic composite materials consisting of isotropic phases are derived by employing extreme principles of thermoelasticity. W. T. Freeman and M. D. Campbell [6] the high modulus and negative thermal expansion coefficient of graphite filaments provide the potential for fabrication of laminated composites exhibiting negligible thermal sensitivity. CE Maneschy, Y Miyano, M Shimbo, TC Woo [7] paper presents theoretical and experimental methods of finding the residual stress in an epoxy plate subjected to rapid cooling on both surfaces. The theoretical residual stress distributions in a plate are calculated by using the fundamental equations based on the linear viscoelastic theory. Hahn, H. T. ,and K. S. Kim. 1989 [8] Residual stresses induced during processing can have deleterious effects on the structural integrity and dimensional stability of composite structures. While the residual stresses in fully cured laminate have been well characterized, the manner in which these stresses develop during processing is still not fully understood.

## METHODOLOGY

### Analytical Methods

In modeling, a linear structural shell element is used for the analysis. Refined meshes, accurate representation of irregular domains are accomplished. The linear layered six DOF, 8-node structural shell element is shown in Figure 1. Nodes are represented by I, J, K, L, M, N, O, and P.

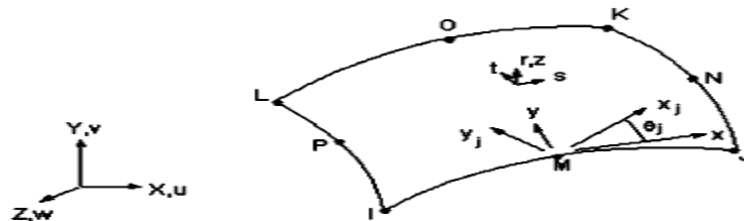


Figure 1: Geometry of 8-node Element with Six Degrees of Freedom

Graphite, which is composed of a single layer of  $sp^2$ -hybridized carbon atoms arranged in a hexagonal lattice, has received tremendous attention in both scientific and industrial areas. It is the strongest material ever measured and has other remarkable qualities, including high thermal stability and electron mobility as well as large surface area and high aspect ratio,

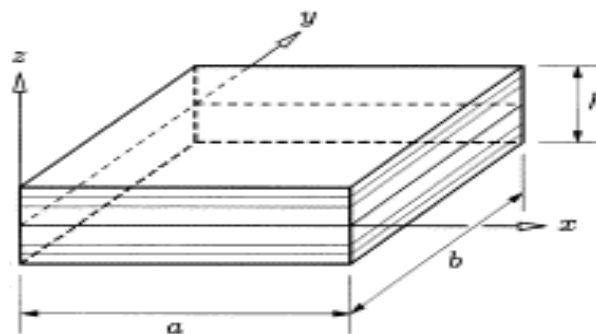


Figure 2: Schematic Diagrams of Plies

The properties of materials are

The engineering elastic constants of the unidirectional graphite/epoxy lamina are

$$E_1 = 181 \text{ GPa}, E_2 = 10.3 \text{ GPa}, \nu_{12} = 0.28, G_{12} = 7.17 \text{ GPa}.$$

The coefficients of thermal expansion for a  $0^\circ$  graphite/epoxy ply are

$$\alpha_1 = 200 \times 10^{-4} \text{ m/m/}^\circ\text{C} \quad \alpha_2 = 225 \times 10^{-4} \text{ m/m/}^\circ\text{C}$$

The coefficients of thermal expansion for a  $0^\circ$  graphite/epoxy ply are

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_{12} \end{bmatrix} \text{ m/m/}^\circ\text{C}$$

The transformed coefficients of thermal expansion for  $0^\circ$  and  $90^\circ$  laminate are

$$\begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix}$$

Compliance matrix elements are,

$$S_{11} = \frac{1}{E_1}$$

$$S_{12} = \frac{-\nu_{12}}{E_1}$$

$$S_{22} = \frac{1}{E_2}$$

$$S_{66} = \frac{1}{G_{12}}$$

And the  $\nu_{21}$  term is called the minor poisson's ratio. We have the reciprocal relation ship

$$\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2}$$

$$\nu_{21} = \frac{\nu_{12}}{E_1} \times E_2$$

The reduced stiffness matrix  $[Q]$  elements are

$$Q_{11} = \frac{E_1}{1 - \nu_{12}\nu_{21}}$$

$$Q_{12} = \frac{\nu_{12}E_2}{1 - \nu_{12}\nu_{21}}$$

$$Q_{22} = \frac{E_2}{1 - \nu_{12}\nu_{21}}$$

$$Q_{66} = G_{12}$$

The compliance matrix for an orthotropic plane stress problem can be written as,

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix}$$

Reduced stiffness matrix for 0° graphite/epoxy ply is

$$[Q] = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix}$$

The transformed reduced stiffness matrix  $[\bar{Q}]$  for each of the two plies is,

$$[\bar{Q}] = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}$$

The fictitious thermal forces are given by,

$$[N^T] = \begin{bmatrix} N_x^T \\ N_y^T \\ N_{xy}^T \end{bmatrix} = \Delta T \sum_{k=1}^n \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}_k \begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix}_k (h_k - h_{k-1})$$

The fictitious thermal moments are given by,

$$[M^T] = \begin{bmatrix} M_x^T \\ M_y^T \\ M_{xy}^T \end{bmatrix} = \frac{1}{2} \Delta T \sum_{k=1}^n \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{12} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{16} & \bar{Q}_{26} & \bar{Q}_{66} \end{bmatrix}_k \begin{bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{bmatrix}_k (h_k^2 - h_{k-1}^2)$$

Now find [A] → extensional stiffness matrix, [B] → coupling stiffness matrix and

[D] → bending stiffness matrix

Where Extensional stiffness matrix [A] is

$$A_{ij} = \sum_{k=1}^n [(\bar{Q}_{ij})]_k (h_k - h_{k-1}) \quad i = 1, 2, 6; \quad j = 1, 2, 6;$$

Coupling stiffness matrix [B] is

$$B_{ij} = \frac{1}{2} \sum_{k=1}^n [\bar{Q}_{ij}]_k (h_k^2 - h_{k-1}^2) \quad i = 1, 2, 6; \quad j = 1, 2, 6;$$

The bending stiffness matrix [D] is

$$D_{ij} = \frac{1}{3} \sum_{k=1}^n [\bar{Q}_{ij}]_k (h_k^3 - h_{k-1}^3) \quad i = 1, 2, 6; \quad j = 1, 2, 6;$$

These stiffness matrices, [A], [B], and [D], are to be used to give the midplane strains and curvatures:

$$\begin{bmatrix} N^T \\ M^T \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{bmatrix} \varepsilon^0 \\ \kappa \end{bmatrix}$$

The laminate strains can be written as,

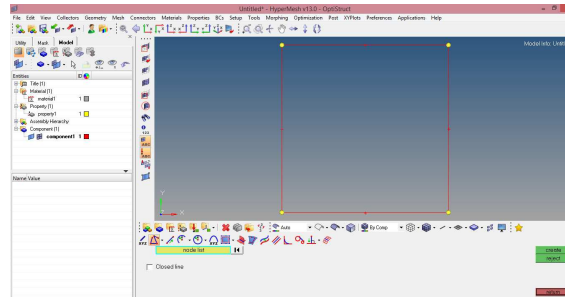
$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{Bmatrix} + z \begin{Bmatrix} \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{Bmatrix}$$

The mechanical strains result in the residual stresses. Thus, if one subtracts the strains that would have been caused by the free expansion from the actual strains, one can calculate the mechanical strains.

$$\begin{Bmatrix} \varepsilon_x^r \\ \varepsilon_y^r \\ \gamma_{xy}^r \end{Bmatrix} = \Delta T \begin{Bmatrix} \alpha_x \\ \alpha_y \\ \alpha_{xy} \end{Bmatrix}$$

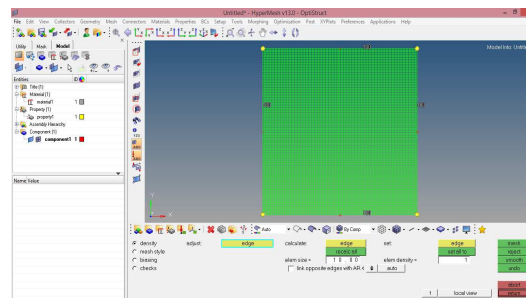
The residual strains are given by,





**Figure 4: Creating Lines**

- Give the **element size=50.0**



**Figure 5: Meshing**

- Click to **return**

#### **Step 9: ply Creation**

Use different colors for each laminate and mark the thickness of the ply in meters, Ply1 should have an Orientation of 0. Ply2 should have an Orientation of 90., Once Ply1, Ply2, Ply3 and Ply4 have been created, close the “Create Ply” window.

#### **Step 10: Create a Ply Laminate Creation with no. of plies or Stacking**

#### **Step 11: Load Collector Creation**

- Click to **return**

#### **Step 12: Apply Constraints**

Click on **analysis**, in analysis goes to **constraints**, to create nodes on the element, then click on a node, select by window, after select which area is want to constraint.

#### **Step 13: Apply Temperature**

- In **analysis** click on **temperature**. With temperature click on **create** and double click on **nodes**, select are displayed., Click on **proceed**., Give the value is **-75**
- Click on **create**.

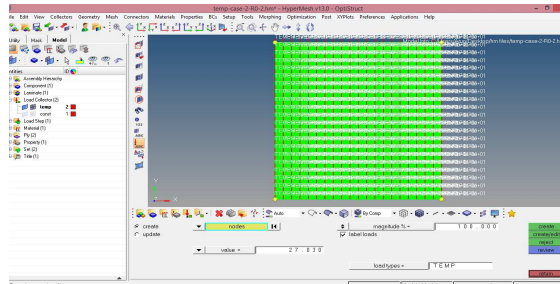


Figure 6: Displayed Temperature

- Click to **return**.

#### Step 14: Load Steps

- In **analysis** click on **load steps**., Give SPC=constraint and TEMP=temperature.
- Click on **create**.

#### Step 15: Optistruct

- In analysis click on **optistruct**
- The solution is running, after completion of solution go for **results**.

### RESULTS AND DISCUSSIONS

In results, the residual Stress in X Direction (MPa) and Y Direction were obtained and are tabulated. The numerical analysis results are compared with FEM Results to estimate the percentage of error for validation. The definitional problem was solved using the FEM method. The analytical and FEM results are tabulated in Table 1 and FEM simulation was done using FEM-based HYPERMESH software.

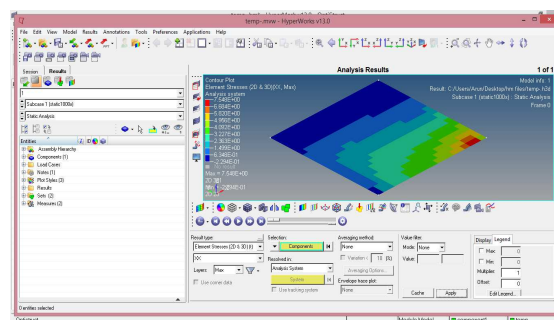


Figure 7: Residual Stress in x-direction

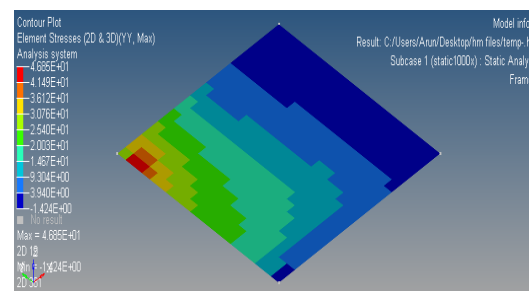


Figure 8: Residual Stress in Y Direction



**Table 1: Comparison of Results for Validation**

S. No	Design Parameter	Results (MPa)		Percentage of Error
		Analytical Results	FEM Results	
1	Residual Stress in X Direction	7.455	7.535	0.01
2	Residual Stress in Y Direction	$4.697 \times 10^{-1}$	$4.718 \times 10^{-1}$	0.004

From the Results, it is concluded that the percentage of error is very low as 0.004%, hence HYPERMESH is one of an accurate simulated tools for analysis of laminated graphite /epoxy composite plate.

## CONCLUSIONS AND FUTURE SCOPE OF WORK

Using analytical approach the residual stresses of laminated composite are successfully analyzed. The Layered composite was also analyzed using simulated analysis using HYPERMESH software. The two plies of laminated Graphite/Epoxy is subjected to temperature change and residual stresses are calculated through analytical method and simulation method using HYPERMESH. The results are compared with the percentage of error is as low as 0.004%, hence the simulated values are validated. The same work may be extended for polymer matrix composites having different aspect ratios and module ratios.

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